CIENCE AND CREATIONISM

View from the National Academy of Sciences

nmittee on Science and Creationism
ional Academy of Sciences

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Front Cover: The United States and other parts of North America can be photograph of the earth taken by the Apollo 16 astronauts during their voyage in 1972.

Back Cover: Map of the world by Isidore of Seville (A.D. 560–636), redrawn a in 1898 in *Mappaemundi: Die ältesten Weltkarten*—a six-volume work Konrad Miller.

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ace

efore you begin to read this discussion of science and creationism, please take a careful look at the front and back covers of this booklet. The front cover depicts the world as we know it to be today. The back cover illustrates the world as people believed it to be in the efore Columbus sailed to the New World. Both views have a place in es—but one belongs in the world as we have come to know it and longs in history. Both views, by the way, are the products of science. hen can the two views be so different? The answer lies at the very of the nature of this system of study we call "science."

cience, everything we observe, measure, or discover must be success- ested again and again before it is accepted as valid and as factual ce of what is real. During the application of this scientific method, sts review their data carefully—and with a healthy skepticism. Most tant, the scientific method requires that the fact-seekers remain open- d, are willing to submit their theories to rational examination, and lling to accept changes indicated by the signposts of evidence. It is o see how this approach encourages the acceptance of change, which n fosters original thought, new ideas, and new hypotheses, all con- g on a better understanding of nature.

might think of Columbus's voyage to the New World as a test of the nesis that India, which lay to the east, could be reached by sailing ard on a round world. As a result of his exploration and many sub- nt observations, including those from voyages into space, we now know ur world actually looks as it is shown on the front cover of this booklet. that is why scientists, such as those of the Council of the National my of Sciences who asked that this booklet be prepared, feel that ng the scientific theory of evolution alongside creationism is inappro- Teaching creationism is like asking our children to believe on faith, ut recourse to time-tested evidence, that the dimensions of the world e same as those depicted in maps drawn in the days before Columbus l with his three small ships, when we *know* from factual observations ney are really quite different.

false, however, to think that the theory of evolution represents an ncilable conflict between religion and science. A great many religious

leaders and scientists accept evolution on scientific grounds without rel quishing their belief in religious principles. As stated in a resolution by Council of the National Academy of Sciences in 1981, however, "Relig and science are separate and mutually exclusive realms of human thou whose presentation in the same context leads to misunderstanding of b scientific theory and religious belief."

The theory of evolution has successfully withstood the tests of scie many, many times. Thousands of geologists, paleontologists, biologi chemists, and physicists have gathered evidence in support of evolution a fundamental process of nature. Our understanding of evolution has b refined over the years, and indeed its details are still undergoing testing evaluation. For example, some scientists currently debate competing id about the rate at which evolution occurred. One group believes that evolut proceeded in small, progressive stages evenly spread throughout the billi of years of geological time; another group believes that there were alternat periods of relatively rapid and slow changes throughout time.

Creationists sometimes cite this debate as evidence for disagreement ab evolution among scientists; some even suggest that scientists who advoc the latter hypothesis are actually supporting a process similar to that creationism. What these creationists fail to understand, however, is t neither scientific school of evolutionary thought questions the scient evidence that evolution took place over billions of years. Rather, the deb centers on only the finer details of *how* it took place.

Debate among scientists is expected. And the products of such debate o the years have been truly astonishing. Scientific debate influenced the pl ning of Columbus's voyage and, more recently, the explorations of spa But debate does not mean resurrecting old theories that have long b invalidated by observations and experiments. Theories that are supported evidence, and which survive the rigorous testing of the scientific meth are passed on to future generations. Examples are the germ theory of disea the theory of gravity, which controls the movement of planets; and theory of evolution. Those that are discounted by the evidence, and wh fail by the scientific method, are of interest only to the historians of scien

In a nation whose people depend on scientific progress for their hea economic gains, and national security, it is of utmost importance that students understand science as a system of study, so that by building past achievements they can maintain the pace of scientific progress ensure the continued emergence of results that can benefit mankind.

Frank Press
President
National Academy of Scien

ience and Creationism: View from the National Academy Sciences

tate legislatures are considering, and some have passed, bills that would require the introduction of biblical creationism in science classes wherever evidence for the origin of the planet, of life and its diverse forms, or of mankind is presented. Local school boards have ed ordinances intended to restrict the teaching of biological concepts volution or to require what is called a "balanced treatment" of creaism and evolution. Publishers of science textbooks are under pressure eemphasize accepted scientific theories of evolution while adding se material on "creation science."

ne teachings of creationism as advocated by and exemplified in the ings of the leading proponents of "creation science" include the folng judgments: (1) the earth and universe are relatively young, perhaps 6,000 to 10,000 years old; (2) the present physical form of the earth be explained by "catastrophism," including a worldwide flood; and ll living things (including humans) were created miraculously, essenin the forms we now find them. These teachings may be recognized aving been derived from the accounts of origins in the first two chapof Genesis in the Bible.

enerations of able and often devout scientists before us have sought ence for these teachings without success. Foremost among these was rles Darwin, a member in good standing of the Church of England an officer of his parish church at Down, in Kent, for many years. His ch more than a century ago gave us instead a hypothesis for the origin pecies by means of natural selection. Others have given us hypotheses ut the origin and history of the earth and the universe itself. These otheses have been tested and validated by many different lines of iry. With modifications to include new findings, they have become central organizing theories that make the universe as a whole intele, lend coherence to all of science, and provide fruitful direction to lern research. The hypothesis of special creation has, over nearly two curies, been repeatedly and sympathetically considered and rejected vidential grounds by qualified observers and experimentalists. In the ns given in the first two chapters of Genesis, it is now an invalidated othesis. To reintroduce it into the public schools at this time as an ent of science teaching would be akin to requiring the teaching of emaic astronomy or pre-Columbian geography.

onfronted by this challenge to the integrity and effectiveness of our onal education system and to the hard-won evidence-based founda- of science, the National Academy of Sciences cannot remain silent. do so would be a dereliction of our responsibility to academic and llectual freedom and to the fundamental principles of scientific thought. a historic representative of the scientific profession and designated sor to the Federal Government in matters of science, the Academy es unequivocally that the tenets of "creation science" are not sup-

in any constructive sense for well-informed and conscientious scienc teachers, and that its teaching would be contrary to the nation's need fo a scientifically literate citizenry and for a large, well-informed pool c scientific and technical personnel.

The Central Scientific Issues Five central scientific issues are critical t consideration of the treatment in school curricula of the origin and evc lution of the universe and of life on earth:

- the nature of science;
- scientific evidence on the origin of the universe and the earth
- the consistent and validated scientific evidence for biologica evolution: specifically, evidence for change over vast realms of time an for relation by common descent, evidence from molecular biology fo degree of relationship, and evidence showing mechanisms of evolution;
- human evolution; and
- the origin of life.

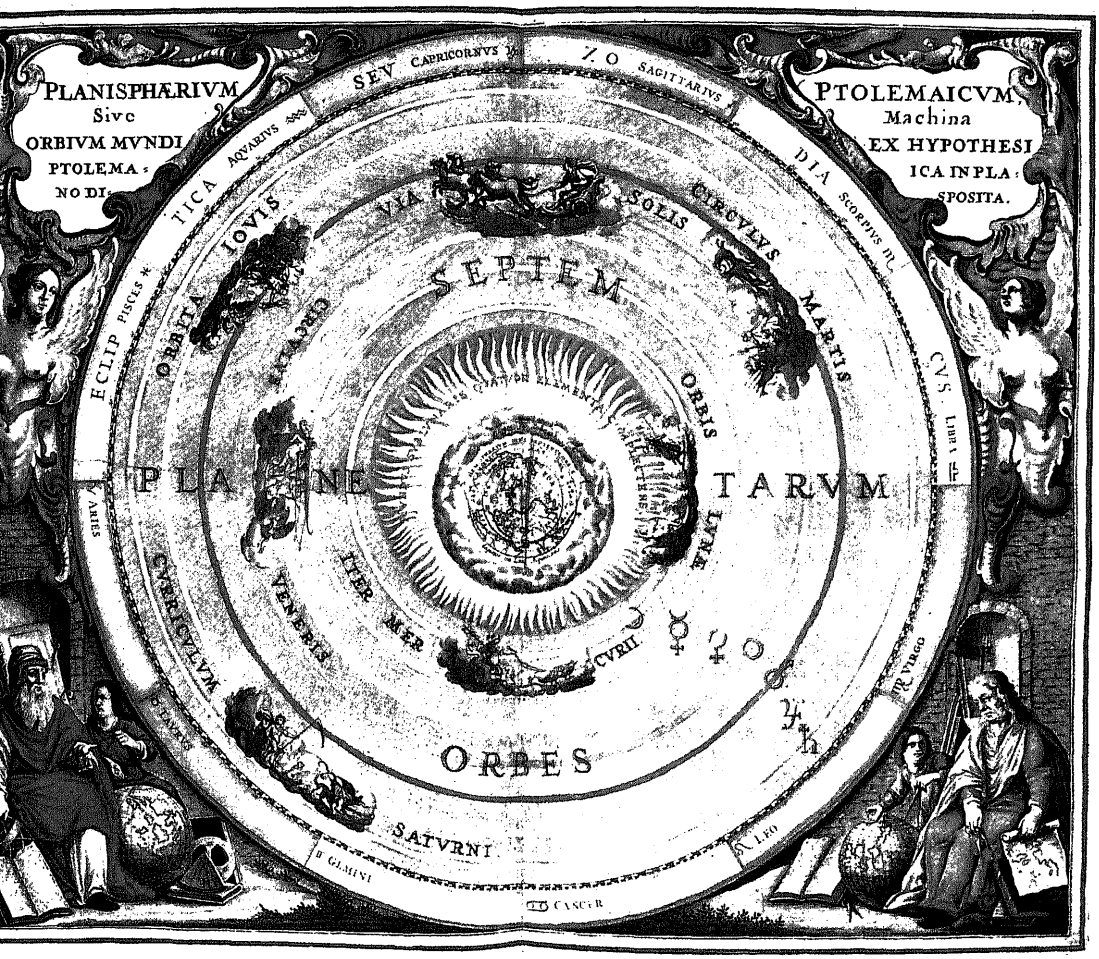
Discussions and conclusions concerning each of these issues make u the balance of this document and present the basis for the Academy' position that the teaching of creationism is not an appropriate activity i our public schools.

The Nature of Science

It is important to clarify the nature of science and to explain wh creationism cannot be regarded as a scientific pursuit. The claim tha equity demands balanced treatment of the two in the same classroon reflects misunderstanding of what science is and how it is conducted Scientific investigators seek to understand natural phenomena by direc observation and experimentation. Scientific interpretations of facts ar always provisional and must be testable. Statements made by any au thority, revelation, or appeal to the supernatural are not germane to thi process in the absence of supporting evidence. In creationism, howeve both authority and revelation take precedence over evidence. The con clusions of creationism do not change, nor can they be validated whe subjected to test by the methods of science. Thus, there are profoun differences between the religious belief in special creation and the sci entific explanations embodied in evolutionary theory. Neither benefit from the confusion that results when the two are presented as equivalen approaches in the same classroom.

In broadest terms, scientists seek a systematic organization of knowl edge about the universe and its parts. This knowledge is based on ex planatory principles whose verifiable consequences can be tested by in dependent observers. Science encompasses a large body of evidence collecte

s always take precedence. The beautifully symmetrical and once in-
ing hypothesis of an earth-centered universe, apparently supported by
"common sense" observation that the sun and stars orbit the earth,
before an accumulation of new evidence. Today's theory of an ex-
ding universe of 10 thousand billion billion or more stars, with all its
zles and uncertainties, is far more consistent with the evidence now
ilable.



The Ptolemaic System. Th
tronomical system was dev
by Ptolemy (ca. A.D. 100–
who postulated that the ea
was the center of the univ
and that the moon, planets
stars revolved around it.

cientists operate within a system designed for continuous testing, where
rections and new findings are announced in refereed scientific publi-
ons. The task of systematizing and extending the understanding of the
verse is advanced by eliminating disproved ideas and by formulating
tests of others until one emerges as the most probable explanation
any given observed phenomenon. This is called the scientific method.
n idea that has not yet been sufficiently tested is called a hypothesis.
ferent hypotheses are sometimes advanced to explain the same factual
dence. Rigor in the testing of hypotheses is the heart of science. If no
fiable tests can be formulated, the idea is called an *ad hoc* hypothesis—
that is not fruitful; such hypotheses fail to stimulate research and are
ikely to advance scientific knowledge.

fruitful hypothesis may develop into a theory after substantial ob-
vational or experimental support has accumulated. When a hypothesis
survived repeated opportunities for disproof and when competing hy-

ir Isaac Newton (1642–1727) as an English mathematician natural philosopher who for- lated the laws of gravity and tion and the elements of dif- rential calculus. He presaged ur present-day satellites in a etch (below) depicting the re- ts that could be expected if a projectile were fired from a untaintop at several different elocities. This first appeared er his death in *A Treatise of e System of the World*, a vol- ume published in London in 8. Newton had argued that a rojectile launched with suffi- ient velocity would orbit the arth. This principle has been onstrated many times during e twentieth century in space lorations such as the journey he orbiter *Challenger* (right), shown during its second lift-off in June 1983.

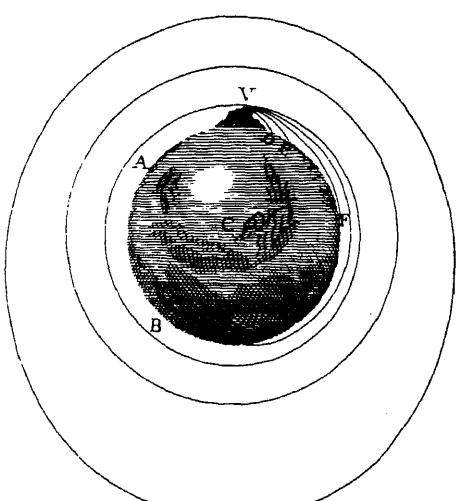
dicted consequences, that hypothesis may become the accepted theo explaining the original facts.

Scientific theories are also predictive. They allow us to anticipate y unknown phenomena and thus to focus research on more narrowly defin areas. If the results of testing agree with predictions from a theory, t theory is provisionally corroborated. If not, it is proved false and must either abandoned or modified to account for the inconsistency.

Scientific theories, therefore, are accepted only provisionally. It is a ways possible that a theory that has withstood previous testing may eve tually be disproved. But as theories survive more tests, they are regard with higher levels of confidence. A theory that has withstood as mar severe tests as, for example, that of biological evolution by means natural selection is held with a very high degree of confidence.

In science, then, facts are determined by observation or measureme of natural or experimental phenomena. A hypothesis is a proposed expl nation of those facts. A theory is a hypothesis that has gained wide a ceptance because it has survived rigorous investigation of its prediction

Higher levels of generalization are formulated into scientific laws. law identifies a class of regularities in nature from which there has bee no known deviation after many observations or trials. It is usually e pressed mathematically. The laws of Newtonian and relativistic motio and those of thermodynamics are examples. Scientific laws tell us t ways but not the whys of nature. They are used in launching and mani ulating space probes, investigating the far reaches of the universe, mappi deep-sea topography from the surface, or probing the earth's internal stru ture. We must heed them in formulating new hypotheses and theories.



y the standards described above, special creation is neither a successful ory nor a testable hypothesis for the origin of the universe, the earth, f life thereon. Creationism reverses the scientific process. It accepts uthoritative a conclusion seen as unalterable and then seeks to support conclusion by whatever means possible.

n contrast, science accommodates, indeed welcomes, new discoveries: theories change and its activities broaden as new facts come to light new potentials are recognized. Examples of events changing scientific ught are legion. Here, for example, we mention four that are both recent germane to the subject of this document.

. The study of the origin of life as a product of chemical evolution ame possible only with advances, mostly since World War II, in our erstanding of early atmospheres, with the development of geochro- gical dating and other research methods, and with the discovery of a g sequence of mainly microbial Precambrian fossils.

. Evidence for deciphering the earliest stages in the evolution of the r system arrived on earth in a meteorite that fell in Sonora, Mexico, 969.

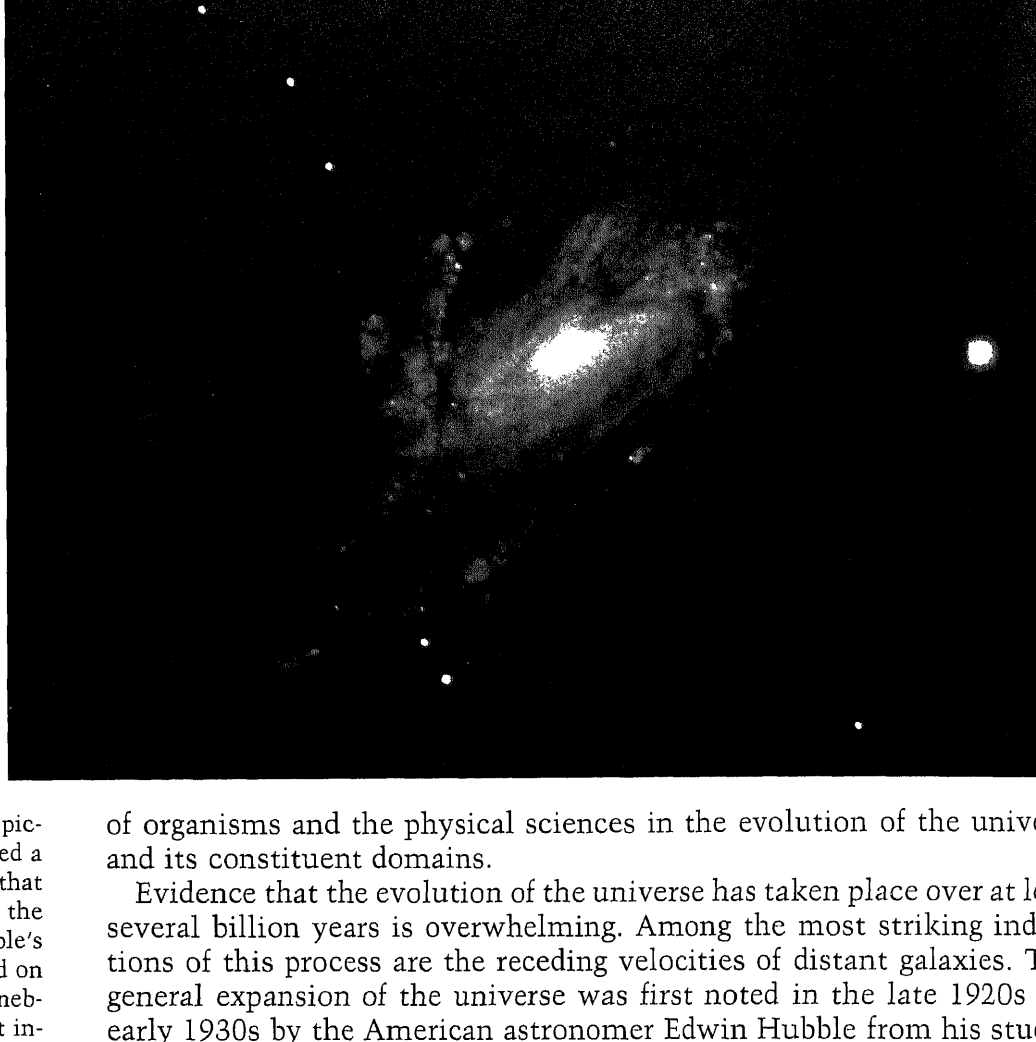
. The fortuitous discovery in 1965 of a universal background radiation temperature of approximately −270° Celsius (3° Celsius above ab- ute zero) brought the first concrete evidence about the nature of the iest universe.

. Discoveries during the past three decades of hominoid remains in t Africa, Pakistan, and elsewhere have combined with advances in lecular biology to initiate a new subscience—paleoanthropology. This d of inquiry is providing an ever-growing inventory of evidence both a close evolutionary connection between modern humans (*Homo sap- s sapiens*) and their australopithecine ancestors and for a clear genetic nity between human beings and the chimpanzee.

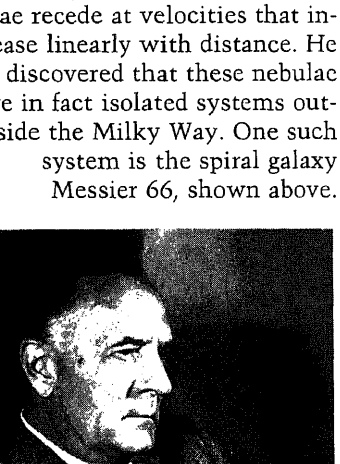
rior acceptance of the fixed *ad hoc* hypotheses of creationism—ideas t are certified as untestable by their most ardent advocates—would e blocked these and other important advances that have led to the nt scientific achievements of recent years. Truly scientific understand- cannot be attained or even pursued effectively when explanations not ved from or tested by the scientific method are accepted.

ientific Evidence on the Origin of the niverse and the Earth

The processes by which new galaxies, stars, and our own planetary system are formed are sometimes referred to as the "evolution" of the universe, the stars, and the solar system. The word *evolution* in this context has a very different meaning than it does when lied to the evolution of organisms. In both instances there is an un-



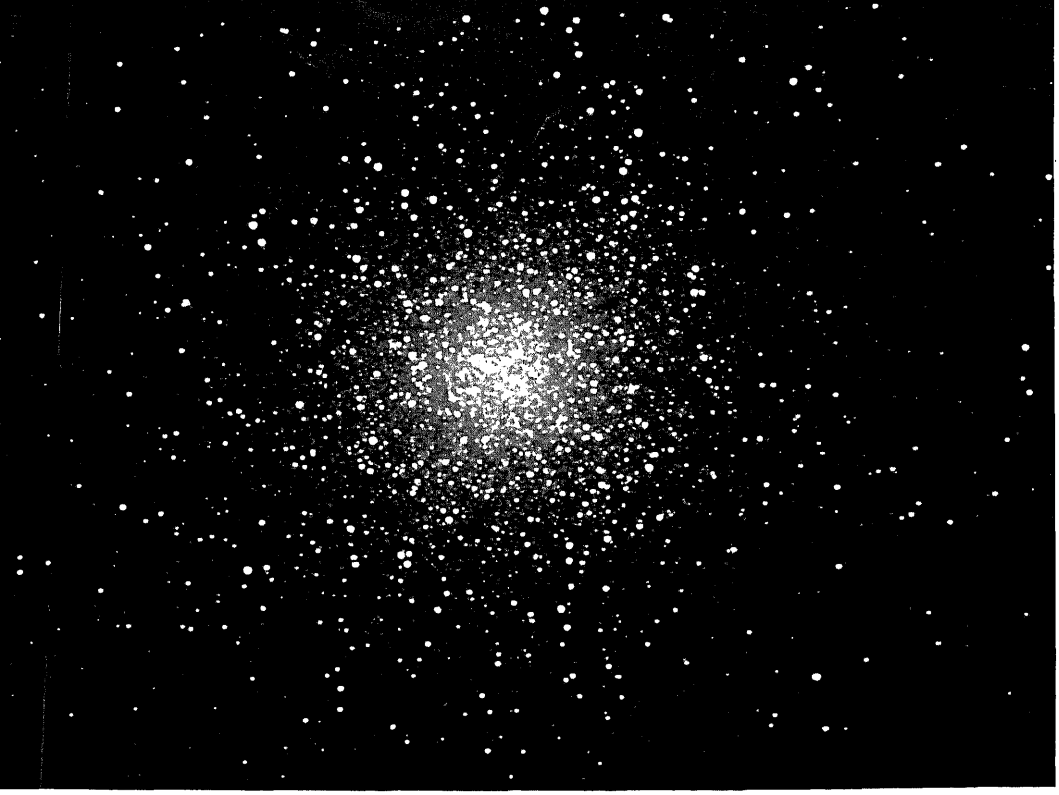
dwin Hubble (1889–1953), pictured below, accumulated a ealth of fundamental data that rved as a basis for many of the ories of cosmology. "Hubble's of the red shift" was based on finding that extragalactic nebae recede at velocities that inease linearly with distance. He discovered that these nebulae in fact isolated systems outside the Milky Way. One such system is the spiral galaxy Messier 66, shown above.



of organisms and the physical sciences in the evolution of the univ and its constituent domains.

Evidence that the evolution of the universe has taken place over at l several billion years is overwhelming. Among the most striking ind tions of this process are the receding velocities of distant galaxies. T general expansion of the universe was first noted in the late 1920s early 1930s by the American astronomer Edwin Hubble from his stu of the changing wavelengths of light from distant stars and galaxies (H ble, 1929; Hubble and Humason, 1931). Extrapolating backwards, ast omers today estimate that the expansion probably began some 10 t billion years ago. This concept of expansion from a more dense early s was dramatically confirmed in 1965, when faint radio static left over f the early universe was discovered by radio astronomers at the Bell oratories (Penzias and Wilson, 1965). The intensity of this static was what would be expected to result from the expansion of the unive Confirming earlier predictions, the discovery strongly reinforced the entific theory that the universe evolved from an initially dense state starting temperature of approximately 100 billion degrees Celsius (W berg, 1977).

The invariant spontaneous decay of the radioactive isotopes of s elements, resulting in the formation of inert daughter isotopes of o elements, provides further evidence that the universe is billions of y old. Analyses of the relative abundances of radioactive isotopes and t inert decay products in the earth, meteorites, and moon rocks all lea the conclusion that these bodies are about 4.5 billion years old. T finding agrees with calculations of the age of the sun based on the th of stellar evolution and is consistent with estimates of the time that w be required for the origin of life and the evolution of organisms. Ano



Large clusters of stars, such
the "globular cluster" in th
stellation Hercules (above),
vide direct observational ev
of stellar evolution.

sure of age comes from the relative abundance of uranium isotopes. relative rarity of the isotope uranium-235, whose half-life is roughly billion years, tells us that the earth's uranium is approximately 7 on years old. We do not know how long after the beginning of the erse it took to form the uranium found on earth, but its presence and ive abundance require that the age of the universe be at least 7 billion s. Although our picture of the origin and evolution of the universe, stars, and the earth is tentative, our reservations should not be con- d with uncertainty about their great age.

trophysicists also have developed plausible hypotheses concerning formation of galaxies, individual stars, and planetary systems. The and planets in our solar system are believed to have been formed by ensations from an interstellar cloud of dust and gas like those now le in parts of our galaxy. New evidence from the geochemical study otopes in the Allende meteorite implies that the condensation re- ng in our solar system was initiated by a nearby exploding star (or rnova) about 4.5 billion years ago. Many details are uncertain, but e is general agreement on the broader aspects of this process.

ne evolution of stars is understood more quantitatively. Comparisons mputer simulations of stellar evolution with the observed distribu- of the temperature and luminosities of stars in large clusters indicate the clusters are typically around 10 billion years old.

major reason for the creationists' opposition to the geological record evolution is their belief that earth is relatively young, perhaps only v thousand years old. In rejecting evidence for the great age of the erse, creationists are in conflict with data from astronomy, astro- ics, nuclear physics, geology, geochemistry, and geophysics. The cre- nists' conclusion that the earth is only a few thousand years old was

originally reached from the timing of events in the Old Testament, cluding the counting of recorded generations (Renckens, 1964). Re attempts to support this conclusion include arguments that the pre magnetic field of the earth is the decaying remnant of a magnetic f that was created with it and that if the earth were more than 10,000 y old the initial strength of the field would have been impossibly large. T is one creationist tenet that can be, and has been, scientifically tested that has not withstood scrutiny. Current scientific data support the th that the earth's magnetic field is a product of the motions of its fluid c The field varies and shifts, but between shifts it is maintained an constantly renewed by dynamo effects within the core.

Scientists knew that the earth was old before they knew how old. To more than a dozen independent radiometric methods are used to mea ages in years, based on different decay systems with different decay c stants and on the ratios of the decay products of different uranium topes. When the age of a given rock is found to be the same when measu by a variety of different isotopic systems, scientists accept that age w a high level of confidence. There is very low probability that diffe isotopic systems with different constants would produce the same res by chance. Suffice it to say here that the cumulative geochronolog evidence indicates the ages of the earth and solar system to be about billion years.

The Scientific Standing of Biological Evolution

Contrary to popular opinion, neither the term nor the idea of logical evolution began with Charles Darwin and his forem work *On the Origin of Species by Means of Natural Selec* (1859). The *Oxford English Dictionary* (1933) tells us that the w *evolution*, to unfold or open out, was derived from the Latin *evolv* which applied to the "unrolling of a book." It first appeared in the Eng language in 1647 in a nonbiological connection. It became widely use English in its primary Latin meaning for all sorts of progressions fr simpler beginnings. Evolution was first used as a biological term in 1 to describe the changes observed in the maturation of insects. Howe it was not until the 1873 edition of *The Origin of Species* that Dar first applied the term. Before that he used the expression *descent w modification*, which is still as good a brief definition of biological e lution as any. In later editions of the book, Darwin paid tribute to earlier views of Jean Baptiste de Lamarck (1802, 1809) and others ab the subject we now call biological evolution or simply evolution.

Charles Robert Darwin (1809–2), the English naturalist who

Although it was Darwin, above all others, who first marshaled convincing critical evidence for biological evolution, earlier alert scho recognized that the succession of living forms on the earth had chan systematically with the passage of geological time. The first recorded

y isolated rocks now classified as Devonian were intermediate in their
ree of development between Silurian forms in deeper strata and Car-
iferous ones above—a sequence that has since been independently
firmed thousands of times (Geikie, 1897; Tasch, 1950).

s applied to biology, a distinction is to be drawn between the questions
whether and (2) *how* biological evolution happened. The first refers to
finding, now supported by an overwhelming body of evidence, that
cent with modification occurred during more than 2.7 billion years of
h's history. The second refers to the theory explaining how those
nges developed along the observed lineages. The mechanisms are still
ergoing investigation; the currently favored theory is an extensively
dified version of Darwinian natural selection.

Vith that proviso we will now consider three aspects of biological ev-
tion in more detail: relation by common descent, molecular biology
t explains the degree of relationship, and the mechanisms of evolution.

ation by Common Descent Evidence for relation by common descent
been provided by paleontology, comparative anatomy, biogeography,
bryology, biochemistry, molecular genetics, and other biological dis-
ines. The idea first emerged from observations of systematic changes
he succession of fossil remains found in a sequence of layered rocks.
h layers are now known to have a cumulative thickness of many scores
ilometers and to represent at least 2.7 billion years of geological time.
e first observation that the final sequence changes systematically up-
d in an undeformed succession of stratified rocks (and thus with time)
s announced in 1799 by a practical engineer named William Smith
ikie, 1897). His findings were confirmed and extended by a number of
eontologists and geologists who used the fossils not as proof of evo-
on but as a basis for working out the original sequences of structurally
urbed rock strata.

The Grand Canyon, with th
orado River winding throug
depths, as seen from Morar
on the south rim. The man
ferent strata of rocks that a
mulated during the success
geological ages are clearly v
in the canyon walls.

The general sequence of fossils had thus already been recognized wh
Darwin perceived that the observed progression of biological forms stron
implied common descent. The farther back into the past one looked,
less the fossils resembled recent forms, the more the various linea
merged, and the broader the implications of a common ancestry appear

In Darwin's time, however, paleontology was still a rudimentary
ence, and large parts of the geological succession of stratified rocks w
unknown or inadequately studied. Darwin, therefore, worried about
rarity of truly intermediate forms. Creationists have then and now sei
on this as a weakness in evolutionary theory. Indeed, although gaps
the paleontological record remain even now, many have been filled
the researches of paleontologists since Darwin's time. Hundreds of th
sands of fossil organisms found in well-dated rock sequences represer
succession of forms through time and manifest many evolutionary tr
sitions. Microbial life of the simplest type (i.e., procaryotes, which
cells whose nuclear matter is not bounded by a nuclear membrane)
already in existence 2.7 billion years ago and perhaps even earlier.
oldest evidence suggesting the existence of more complex organisms (
eucaryotic cells with a true nucleus) has been discovered in fossils t
had been hermetically sealed in flinty rocks approximately 1.4 bill
years old. More advanced forms like true algae, fungi, higher plants,
animals have been found only in still younger geological strata. The
lowing list presents the order in which progressively complex forms
life appeared:

Life Form	Millions of Years Sin First Known Appearar (Approximate)
Microbial (procaryotic cells)	2,700
Complex (eucaryotic cells)	1,400
First multicellular animals	670
Shell-bearing animals	540
Vertebrates (simple fishes)	490
Amphibians	350
Reptiles	310
Mammals	200
Nonhuman primates	60
Earliest apes	25
Australopithecine ancestors	5
Homo sapiens sapiens (modern humans)	0.05 (50,000 years)

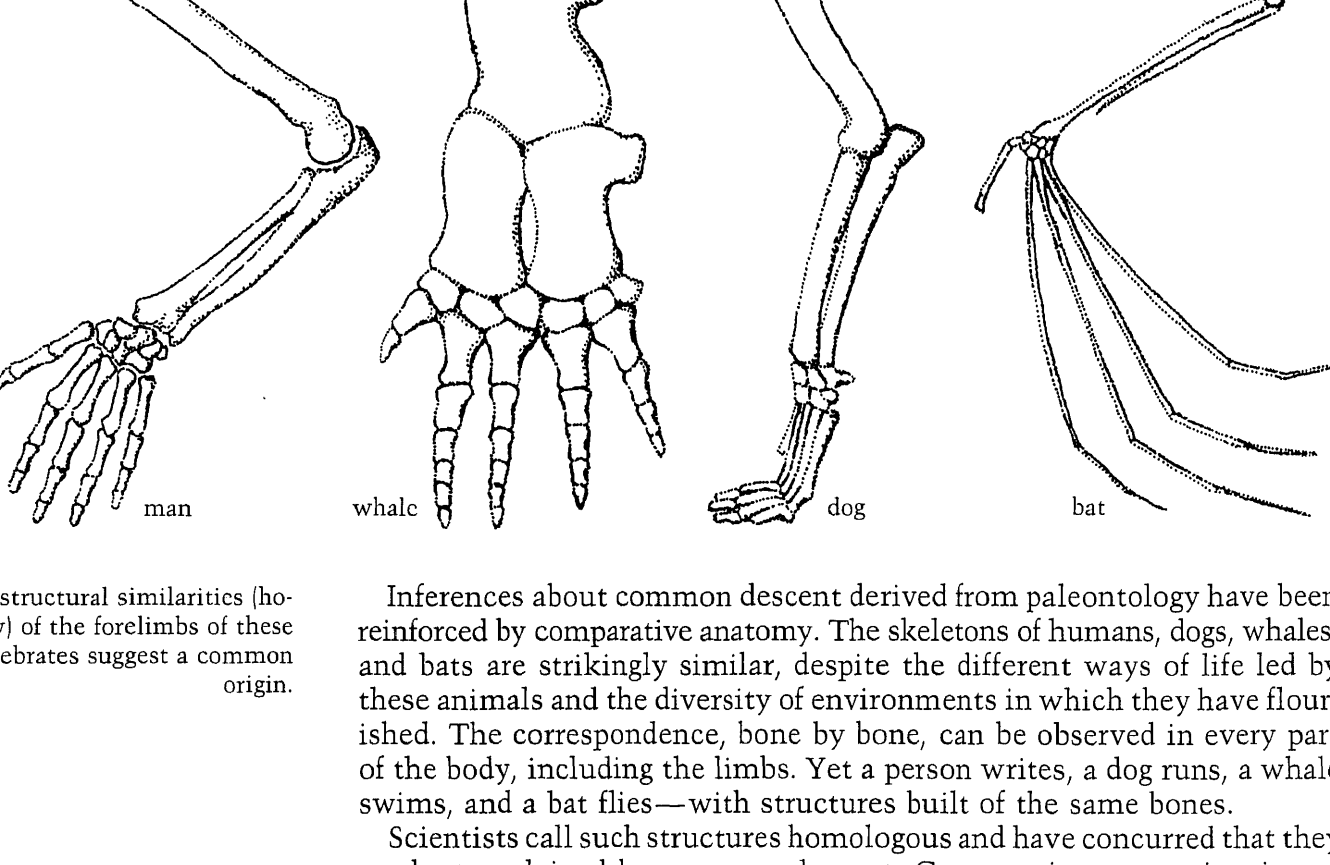
The sequence of observed forms and the fact that all except the f
are constructed from the same basic cellular type strongly imply that
these major categories of life (including plants, true algae, and fungi) h
a common ancestry in the first eucaryotic cell. Morever, there have b
so many discoveries of intermediate forms between fish and amphibia
between amphibians and reptiles, between reptiles and mammals,
even along the primate line of descent that it is often difficult to iden
categorically the line to which a particular genus or species belongs.
deed, nearly all fossils can be regarded as intermediates in some sens
as life forms that come between related forms that preceded them
those that followed.

Archaeopteryx has one skelet feature that is exclusively avian—the wishbone, or furc (fused clavicles). All other rec nizable features of its skeleto are also found in various carn rous dinosaurs. For this reaso *Archaeopteryx* is considered many to have been an interm ate form between dinosaurs a birds. In 1877 this specimen found embedded in the 150-n lion-year-old Jurassic Solnhof limestones of Bavaria.

ne fossil record thus provides compelling evidence of systematic change ugh time—of descent with modification. From this consistent body vidence it can be predicted that no reversals will be found in future ontological studies. That is, amphibians will not appear before fishes mammals before reptiles, and no complex life will occur in the geo- cal record before the oldest eucaryotic cells. That prediction has been eld by the evidence that has accumulated thus far: no reversals have n found.

reationists have sometimes cited an investigation of human footprints to be associated with those of dinosaurs. These footprints were re- ed to have been found in a roughly 90-million-year-old layer of rock Glen Rose, Texas. It was subsequently discovered by a young crea- ist himself that some of the human-looking footprints had been carved pranksters and that the reportedly convincing ones were no longer ent (Morris, 1980). There is no evidence that humans lived at the time ne dinosaurs. In fact, there is much that is opposed to that conclusion. lthough creationists claim that the entire geological record, with its rly succession of fossils, is the product of a single universal flood that

depth of some 7 meters a few thousand years ago, there is clear evidence in the form of intertidal and terrestrial deposits that at no recorded time in the past has the entire planet been under water. Moreover, a universal flood of sufficient magnitude to deposit the existing strata, which together are many scores of kilometers thick, would require a volume of water far greater than has ever existed on and in the earth, at least since the formation of the first known solid crust about 4 billion years ago. The belief that all this sediment with its fossils was deposited in an orderly sequence in a year's time defies all geological observations and physical principles concerning sedimentation rates and possible quantities of suspended solid matter. We do not doubt that there were periods of unusually high rainfall or that extensive flooding of inhabited areas has occurred, but there is no scientific support for the hypothesis of a universal, mountain-topping flood.



structural similarities (ho-
y) of the forelimbs of these
ebrates suggest a common
origin.

Inferences about common descent derived from paleontology have been reinforced by comparative anatomy. The skeletons of humans, dogs, whales and bats are strikingly similar, despite the different ways of life led by these animals and the diversity of environments in which they have flourished. The correspondence, bone by bone, can be observed in every part of the body, including the limbs. Yet a person writes, a dog runs, a whale swims, and a bat flies—with structures built of the same bones.

Scientists call such structures homologous and have concurred that they are best explained by common descent. Comparative anatomists investigate such homologies, not only in bone structure but also in other parts of the body as well, working out relationships from degrees of similarity. Their conclusions provide important inferences about the details of evolutionary history that can be tested by comparisons with the sequence of ancestral forms in the paleontological record.

The mammalian ear and jaw offer another instance in which paleontology and comparative anatomy combine to show common ancestry

re homologous with bones now found in the mammalian ear. What ion could these bones have had during intermediate stages? Paleon- ists have now discovered two intermediate forms of mammal-like es (Therapsida) with a double jaw joint—one composed of the bones persist in mammalian jaws, the other consisting of bones that even- y became the hammer and anvil of the mammalian ear. Similar ex- es are numerous. Some specific findings relating to human beings escribed later in this document.

geography also has contributed evidence for common descent. The sity of life is stupendous. Approximately 250,000 species of living s, 100,000 species of fungi, and perhaps 1.5 million additional species imals and microorganisms have been described and named, each pying its own peculiar ecological setting or niche, and the census is om complete. Some species, such as human beings and our compan- he dog, can live under a wide range of environmental conditions. rs are amazingly specialized. One species of the fungus *Laboulbenia* s exclusively on the rear portion of the covering wings of a single es of beetle (*Aphaenops cronei*) found only in some caves of southern e. The larvae of the fly *Drosophila carcinophila* can develop only in alized grooves beneath the flaps of the third pair of oral appendages e land crab *Gecarcinus ruricola*, which is found only on certain bbean islands.

w can we make intelligible the colossal diversity of living beings and existence of such extraordinary, seemingly whimsical creatures as *ulbenia*, *Drosophila carcinophila*, and others? Why are island groups the Galapagos so often inhabited by forms similar to those on the st mainland but belonging to different species? Why is the indigenous o different on different continents? Creationists contend that the us facts of biogeography result from the occurrence of a special crea- ry event. A scientific hypothesis proposes that biological diversity ts from an evolutionary process whereby the descendants of local or ant predecessors became adapted to their diverse environments. A ble corollary of that hypothesis is that present forms and local fossils ld show homologous attributes indicating how one is derived from ther. Also, there should be evidence that forms without an established ancestry had migrated into the locality. Wherever such tests have carried out, these conditions have been confirmed. A good example ovided by the mammalian populations of North and South America, e strikingly different endemic forms evolved in isolation until the gence of the Isthmus of Panama approximately 3 million years ago. eafter, the armadillo, porcupine, and opossum—mammals of South rican origin—were able to migrate to North America along with y other species of plants and animals, while the placental mountain and other North American species made their way across the isthmus e south.

e evidence that Darwin found for the influence of geographical dis- tion on the evolution of organisms has become stronger with ad- ing knowledge. For example, approximately 2,000 species of flies nging to the genus *Drosophila* are now found throughout the world. at one-quarter of them live only in Hawaii. More than a thousand

species of snails and other land mollusks are also found in Hawaii
only natural explanation for the occurrence of such great diversity a
closely similar forms is that the differences resulted from adaptive
nization of isolated environments by animals with a common anc
The Hawaiian islands are far from, and were never attached to, any
land or other islands, and they have had few colonizers. Organisms
reached these islands found many unoccupied and relatively isolate
logical niches where they could then undergo separate evolutiona
versifications.

The vagaries of biogeography cannot be attributed to environm
peculiarities alone. The Hawaiian islands are no better than other P
islands for the survival of *Drosophila*, nor are they less hospitable
other parts of the world for many organisms not indigenous to ther
example, pigs and goats have multiplied in Hawaii after their introdu
by humans. Thus, organisms are also absent from places well suit
their occupancy where potential ancestors were lacking.

Embryology, the study of biological development from the time o
ception, is another source of independent evidence for common de
Barnacles, for instance, are sedentary crustaceans with little apparen
ilarity to such other crustaceans as lobsters, shrimps, or copepods
barnacles pass through a free-swimming larval stage, in which they
unmistakably like other crustacean larvae. The similarity of larval s
supports the conclusion that all crustaceans have homologous part
a common ancestry. Similarly, human and other mammalian em
pass through a stage during which they have unmistakable but u
grooves similar to gill slits found in fishes—evidence that they ar
other vertebrates shared remote ancestors that respired with the
gills.

Finally, the substantiation of common descent that emerges fro
the foregoing lines of evidence is being validated and reinforced b
discoveries of modern biochemistry and molecular biology, as disc
in the following section.

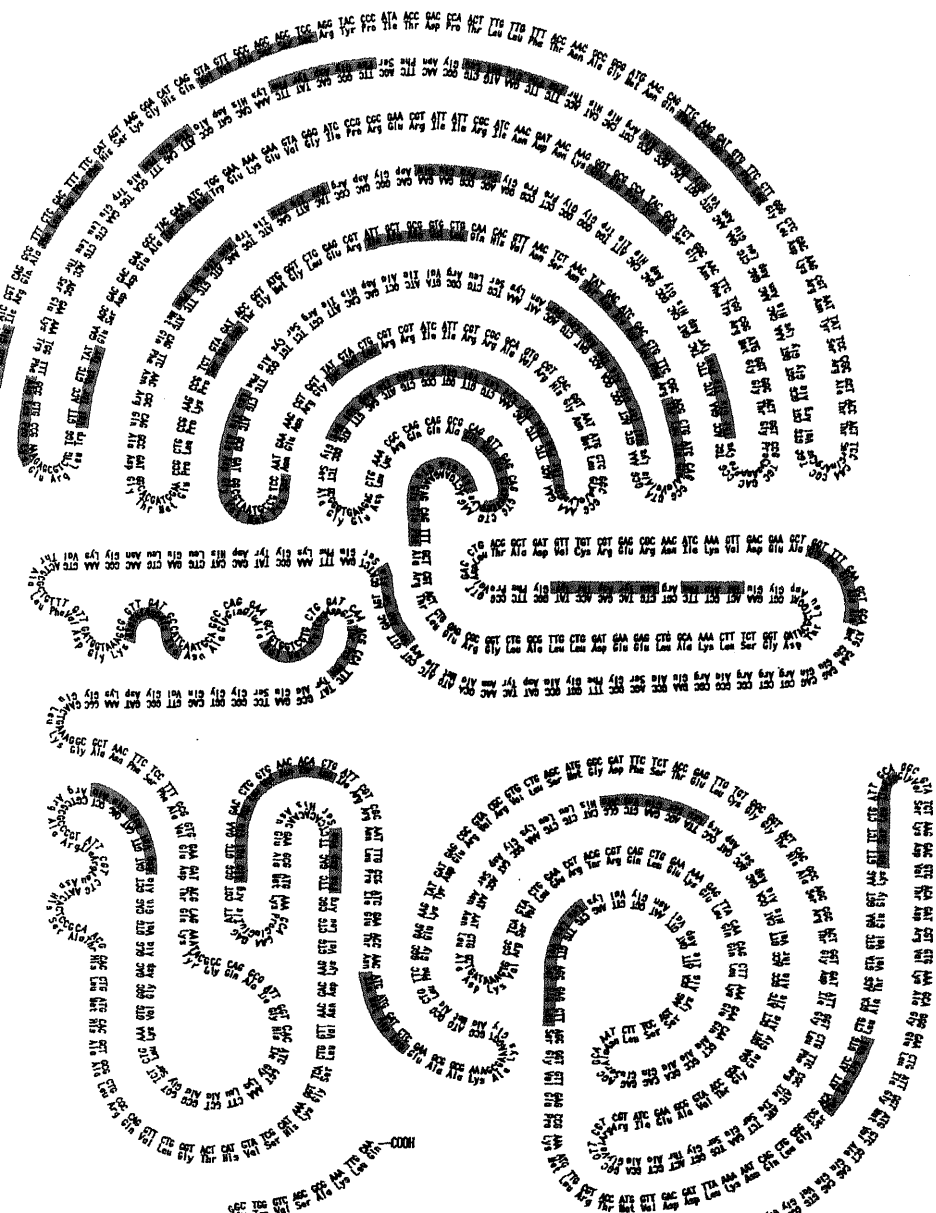
Molecular Biology and the Degree of Relationship Very recent s
in molecular biology have independently confirmed the judgments
leontologists and classical biologists about relationships among lin
and the order in which species appeared within lineages. They hav
provided detailed information about the mechanisms of biologica
lution.

DNA (deoxyribonucleic acid), the hereditary material within all
and the proteins encoded by genes in the DNA both offer extensi
formation about the ancestry of organisms. Analysis of such inform
has made it possible to reconstruct evolutionary events that were
ously unknown and to confirm and date events already surmised b
precisely dated. The precision whereby evolutionary events can b
reconstructed is one reason why the evidence from molecular biol
so compelling.

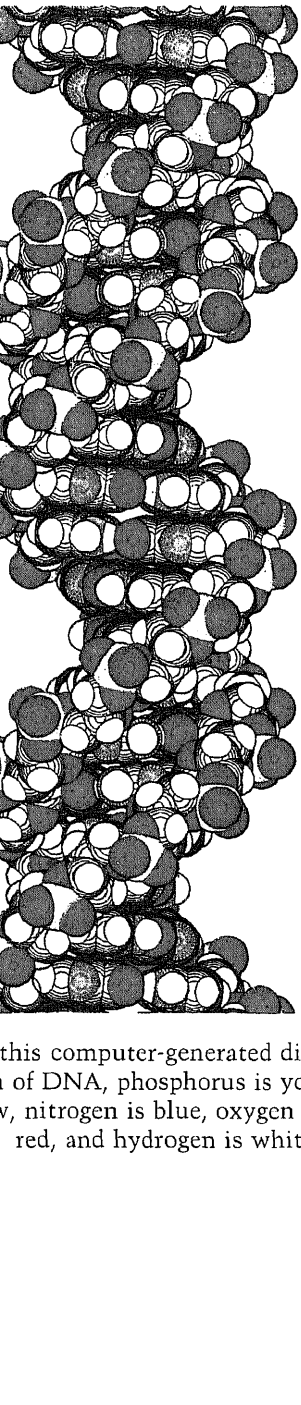
In unveiling the universality of the chemical basis of heredity, mol
biology has profoundly affirmed common ancestry. In all organi
bacteria, plants, and animals, including humans—the hereditary

subunits called nucleotides. The genetic code by which the infor-
ion contained in the nuclear DNA is used to form proteins is essen-
y the same in all organisms. Proteins in all organisms are invariably
posed of the same 20 amino acids, all having a "left-handed" config-
ion, although there are amino acids in nature with both "right-" and
t-handed" configurations. The metabolic pathways through which the
st diversified organisms produce energy and manufacture cell com-
ents are also essentially the same.

his unity reveals the genetic continuity of living organisms, thereby
ng independent confirmation of descent from a common ancestry.
re is no other way consistent with the laws of nature and probability
ccount for such uniformity. The genetic code may serve as an example.
eneral, each of the 64 possible sequences of three of the four nucleo-



The genetic code consists of
quences of nucleotide triplet
(e.g., TTG), which are transl
into sequences of amino acid
such as leucine. In this illus
tion the amino acid sequenc
an aminoacyl-tRNA (transfe
bonucleic acid) synthetase e
zyme is translated from, and
shown next to, the nucleotid
quence of DNA (deoxyribon
acid), which constitutes its g
The darker blue shaded area
the enzyme indicate those r
that have been checked by n
spectrometric analyses.



this computer-generated dia-
of DNA, phosphorus is ycl-
, nitrogen is blue, oxygen is
red, and hydrogen is white.

tides in the nuclear DNA has the same meaning in all organisms. T
significance of this can be seen by comparing the genetic code to hum
languages. Many different languages have evolved, each using certain co
binations of symbols and sounds to convey a specific meaning. If simi
combinations of symbols and sounds are used to express the same mean
in different languages, we infer that the languages involved had a comm
source. The genetic code is a universal language, implying a single sour

Consider a comparison between two books of similar length. Let us
that closer examination reveals that the two books are identical page
page and word by word, except that an occasional word, say one i
hundred, is different. It is highly improbable that the two books w
written independently: either one book was copied from the other or b
were copied from a third source. Now, if each nucleotide in human DI
is represented by one letter, the complete sequence of nucleotides wo
require over a million pages. When the pages in the human genetic bo
are compared with those of diverse organisms, correspondence in
sequence of letters gives unmistakable evidence of common origin.
casional changes provide information about particular species, just as
copies of a specific edition of a book can be identified by common chang

Thus molecular biology validates the already impressive evidence t
all living organisms, from bacteria to humans, are ultimately descen
from common ancestors (Dobzhansky *et al.*, 1977). Since evolutionist
earlier times knew nothing about molecular biology, discoveries result
from studies in this relatively new field of science provide independ
and unanticipated reinforcement of their theories.

But the evidence for evolution from molecular biology goes further.
degree of similarity in the sequence of nucleotides in DNA (or of am
acids in proteins) can now be precisely quantified. For example, the prot
cytochrome-*c* in humans and chimpanzees consists of the same 104 am
acids in exactly the same order, whereas that of rhesus monkeys dif
from them by one amino acid, that of horses by 11 amino acids, and t
of the tuna by 21 amino acids. The extent of deviation corresponds to
time interval since fish, mammals, and human ancestors appeared in
geological record, i.e., the degree of divergence reflects the time that
passed since the respective lineages had a common ancestry. Thus,
ferences from paleontology, comparative anatomy, and other disciplin
as to the evolutionary history of organisms can be tested by examin
the sequences of nucleotides in the DNA or the sequences of amino ac
in protein. The potential power of such tests is overwhelming. Each
the thousands of genes and proteins provides an independent test of evo
tionary history.

Only a few of the countless possible tests have been performed
course. But of the many hundreds that have been conducted, none
provided evidence contrary to the concept of evolution. Instead, molecu
biology confirms the idea of common descent in every aspect.

Evolution pervades all biological phenomena. To ignore that it occur
or to classify it as a form of dogma is to deprive the student of the m
fundamental organizational concept in the biological sciences. No ot
biological concept has been more extensively tested and more thoroug
corroborated than the evolutionary history of organisms. The *mechanis*
by which evolution occurred, however, are not agreed upon in detail. T
remain an area for continuing research, discussion, and discovery.

anisms of Evolution Students of evolutionary biology seek not only onstruct the evolutionary history of organisms but also to discover ecific mechanisms that account for evolutionary change. Research is subject is currently so lively that we can include in this brief ient only some well-tested and widely agreed upon generalities.

win proposed that evolution could be explained by hereditary var- followed by natural selection. His original hypothesis has under- extensive modification and expansion, but the central concepts stand Mendelian genetics and molecular biology were unknown to Darwin, udies in these fields have explained the occurrence of hereditary ions essential to Darwin's ideas. Genetic variations result from changes NA structure, whether by mutation, recombination, or some other completely understood mechanism. Such changes in DNA can now ysically observed and numerically quantified in many favorable cir- tances (Ayala and Valentine, 1979).

ere is still much to be learned from new experiments and observa- Meanwhile, biologists and paleontologists are debating the relative rtance of the various mechanisms in order to devise questions that roduce the most meaningful inquiries into the methods and rates olution.

e point concerning mechanisms deserves emphasis. Mutations and variations arise by chance. They do not necessarily equip the or- m with better means for surviving in its environment. But if a gene nt improves adaptation (for example, by allowing an organism to use of an available nutrient or to escape predators more effectively), ganisms carrying that gene are more likely to survive and reproduce those without it. Thus, much as Darwin proposed, natural selection process that gives direction to evolution and makes it more than roduct of chance. Natural selection accounts for the apparent design ganisms as well as their imperfections. Adaptations, whether ex- ed as simple metabolic reactions or as a complicated organ like the n eye, are considered by the overwhelming majority of biologists to e result of natural selection. For this reason, the theory of natural ion is called upon to explain the observable evidence for biological tion.

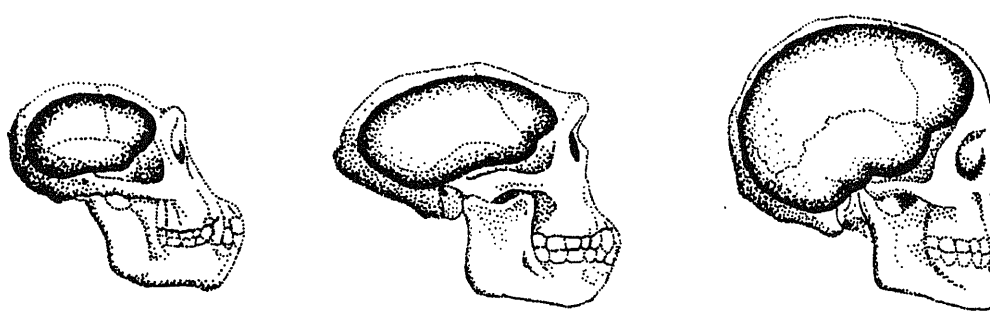
man Evolution

tudies in evolutionary biology have led to the conclusion that man- kind arose from ancestral primates. This association was hotly de- bated among scientists in Darwin's day, before molecular biology and the discovery of the now abundant connecting links. Today, ver, there is no significant scientific doubt about the close evolu- ry relationships among all primates or between apes and humans ews and Cronin, 1982; Simons, 1980, 1981). The "missing links" roubled Darwin and his followers are no longer missing. Today, not ut many such connecting links, intermediate between various branches primate family tree, have been found as fossils. These linking fossils termediate in form and occur in geological deposits of intermediate

age. They thus document the time and rate at which primate and humar evolution occurred.

The possibility of error in determining ages has been reduced by nev methods based on measurements of reversals in the earth's magnetic fiel in ancient rocks. Furthermore, fossils continue to be found with grea frequency. The combination of information from stratigraphy, fossils, an dating techniques and findings from studies in molecular biology ha enabled scientists to develop the following scheme of human evolution The human line separated from that of the apes approximately 5 millio years ago. About 4 million years ago, our ancestors were already bipeda but had brains no larger than those of the contemporary apes. Within million years after that, these small-brained bipeds were making ston tools. In the next half million years, the brain doubled in size and th stone tools became much more complex. Change was very slow unti people anatomically similar to ourselves had evolved. Then in a few thou sand years, humans reached Australia, the Arctic, and the New Worl Tools were improved, and boats, bows, and sleds were invented. Thi revolution was accompanied by the development of agriculture and shortl thereafter, from an evolutionary point of view, the complex social an industrial world we know today.

From the time of our earliest ancestors onward, there were successiv and regular increases in average brain volume and body size, coupled i later stages with a progressive reduction in the thickness of the brain cas the protrusion of brow ridges, and the size of cheek teeth. These change occurred through a succession of well-documented intermediate forms c species. Finally, approximately 50,000 years ago, *Homo sapiens sapiens*– the oldest human being of morphologically modern character—appeare This appearance of fully developed modern man close to 50,000 years ag is, of course, inconsistent with the creationist view that the earth i perhaps only 10,000 years old or less.



volution of the skull was
by two major characteris-
e cranium (and brain) be-
rger and the face smaller.
Homo erectus marks the
oximate midpoint in this
tion from ancient apelike
o modern human beings.

niques, and paleoanthropology are backed up by findings from studies olecular biology. A 99 percent similarity is found between the DNA uman beings and the DNA of chimpanzees. Such studies link humans, chimpanzee, and the gorilla together in the same biological family.

e Origin of Life

cientific research on the origin of life is in an exploratory phase, and all its conclusions are tentative. We know that the organisms that lived on earth 2 billion or more years ago were simple microbial forms. There is even some evidence that life might already have ted when the first known solid crust formed on earth, almost 4 billion s ago. The geological record indicates that liquid water, other chem-, and a suitable atmosphere for prebiotic chemical activity were pre- on earth more than 3.8 billion years ago. Earliest life was unicellular oncellular, existed in the absence of oxygen, and may have been in- ble of producing its own nutrients from solar or chemical energy. erimental results and astronomical observations are consistent with idea that the steps required to link and set into operation the essential ponents of a living cell could have occurred under conditions pre- ng on the primitive earth. They could not occur now because of the ructive effects of today's abundant molecular oxygen, not only on ple unprotected living systems but also on the intermediate products might have generated the component molecules of such systems.

xperiments conducted under plausible primitive-earth conditions have lted in the production of amino acids, large protein-like molecules e from long chains of amino acids, the nucleotide components of A, and DNA-like chains of these nucleotides. Many biologically in- sting molecules have also been detected by astronomers using radio- scopes. We can, therefore, explain how the early oxygen-free earth vided a hospitable site for the accumulation of molecules suitable for construction of living systems. Such molecules could have been formed result of chemical reactions on the earth's surface, or they could have ved in carbonaceous meteorites. Perhaps both sources are responsible heir presence.

nce the starting materials such as amino acids and nucleotides have formed, larger molecules can then be made experimentally by re- ving water through a process called dehydration condensation. Amino s join to form proteins, and nucleotides join to form nucleic acids. n DNA molecules have been synthesized from purified components n from the laboratory shelf.

or those who are studying aspects of the origin of life, the question no ger seems to be whether life could have originated by chemical pro- es involving nonbiological components but, rather, what pathway ht have been followed. The data accumulated thus far imply selective esses. Prebiological chemical evolution is seen as a trial-and-error ess leading to the success of one or more systems built from the many ible chemical components. The system that evolved with the capa-

In 1953, Stanley Miller (show above) and Harold Urey used electrical discharge apparatus the type seen in this 1975 ph graph to accomplish the first oratory synthesis of amino a in a simulated primitive eart vironment.

bility of self-replication and mutation led to what we now define as living system.

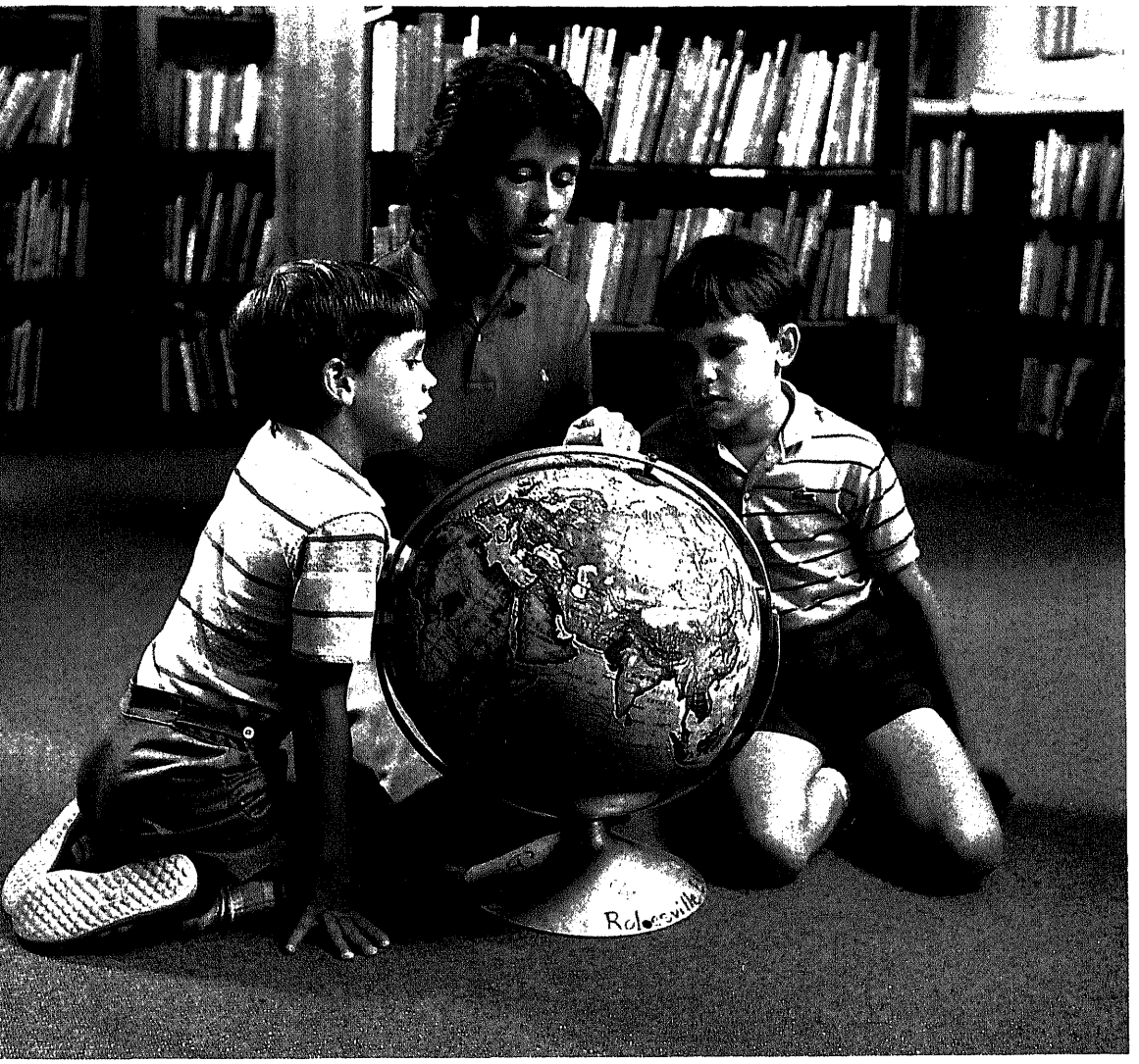
Will we ever be able to identify the path of chemical evolution th succeeded in initiating life as we know it? This question may be una swerable. Even if a living cell were to be made in the laboratory, th event would not prove that nature followed the same pathway billions years ago. Still, the history of science shows that seemingly intractal problems may become amenable to solution as a result of advances theory or instrumentation or the fortuitous discovery of new facts.

Conclusion

Scientists, like many others, are touched with awe at the order a complexity of nature. Religion provides one way for human beir to be comfortable with these marvels. However, the goal of scier is to seek naturalistic explanations for phenomena—and the origi of life, the earth, and the universe are, to scientists, such phenomena within the framework of natural laws and principles and the operatio rule of testability.

It is, therefore, our unequivocal conclusion that creationism, with accounts of the origin of life by supernatural means, is not science. subordinates evidence to statements based on authority and revelati Its documentation is almost entirely limited to the special publicatic of its advocates. And its central hypothesis is not subject to change light of new data or demonstration of error. Moreover, when the evider for creationism has been subjected to the tests of the scientific meth it has been found invalid.

No body of beliefs that has its origin in doctrinal material rather th scientific observation should be admissible as science in any science cour Incorporating the teaching of such doctrines into a science curricul stifles the development of critical thinking patterns in the developi mind and seriously compromises the best interests of public educati This could eventually hamper the advancement of science and technol as students take their places as leaders of future generations.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